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Status Report

DEVELOPMENT OF EQUIPMENT FOR ROCK RESISTIVITY MEASUREMENTS

(Project BE8, Task 1)

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SUMMARY

The principal objective of Project BE8, Residual Oil Saturation Measurement and Estimation Improvement, is to improve the accuracy of resistivity log measurements by developing calibration parameters for Archie's equation, or similar interpretation techniques, as functions of reservoir rock type and reservoir conditions. Several tasks have been planned to achieve this objective. The purpose of task 1 is to develop equipment for rock resistivity measurements at high pressures and temperatures. A flow chart of this equipment is presented along with the operating procedure. The literature on rock resistivity measurements is cited. Data presented will be used to estimate discrepancies in residual oil saturation determination due to the effect of temperature and pressure on parameters used in Archie's equation or similar interpretation techniques. Rock samples available for future resistivity studies are listed.

ROCK RESISTIVITY MEASUREMENT EQUIPMENT

Figure 1 shows the flow chart of the experimental setup used for measuring rock resistivity at reservoir pressures and temperatures. The system was tested at pressures to 5,000 psi and temperatures to 200°F.

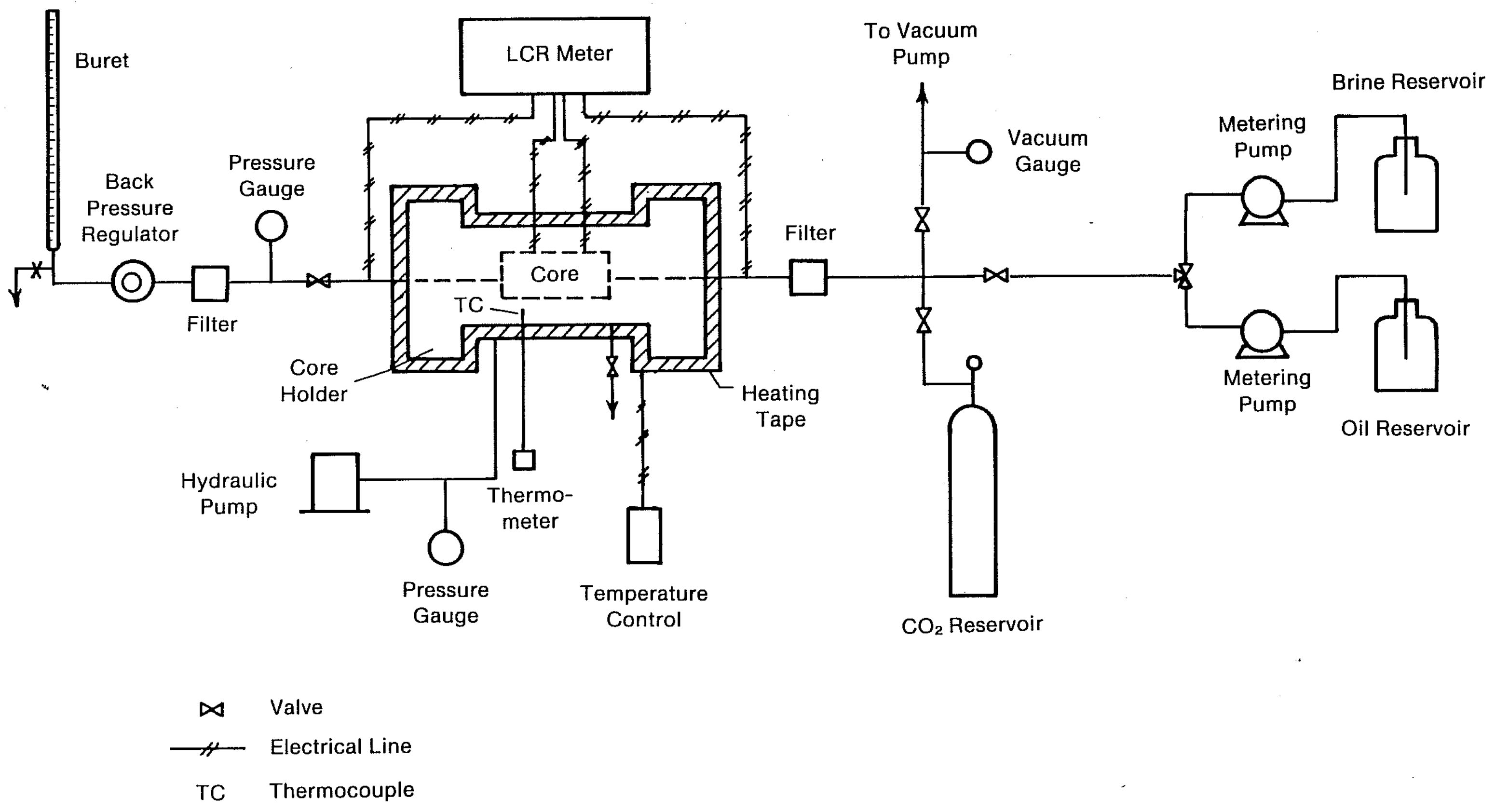

FIGURE 1. - Flow chart of equipment and system for measuring rock resistivity at reservoir pressure and temperature.

The major components of the system are as follows:

- **Core holder (TEMCO-ECR)** -- allows measurement of resistivities under confining pressure to 5000 psi and temperature of 212° F using the four-electrode technique. In the four-electrode design, current is applied to the outside electrodes, and the voltage drop is measured between the two electrodes molded into the viton sleeve and insulated from the core holder body and the current electrodes (see figure 1). The core holder is made of aluminum to allow the measurement of water or oil saturation using the x-ray absorption technique.

- **Backpressure regulator (Tescom 26-1700)** -- self-contained, spring-loaded backpressure regulator which has a relief pressure range of 200 to 10,000 psig and a dead volume of 4 ml.

- **LCR meter (HP 4262A)** -- device for measuring electric resistance, capacitance, and conductance at three radiowave frequencies (120Hz, 1kHz, and 10kHz).

- **Metering pumps (Water Associate, Inc. - Model 6000A)** -- maximum output pressure is 6,000 psig. Flow rate is manually selected from 0.1 to 9.9 ml/min in 0.1 ml/min increment.

- **Hydraulic pump (PIA)** -- Star single-piston, screw-release pump.

- **Digital thermometer (Omega 2166A)**

- **Thermocouple** -- 1/8-inch stainless-steel iron/constantan thermocouple.

OPERATING PROCEDURE

Step 1 -- Core sample preparation and preliminary resistance measurement

a. Dry core plug (1 inch diameter and 1-3/4 inch length). Insert dry core into the viton sleeve. Install the sleeve into the core holder.

b. Deaerate oil and water phases. Soltrol-220 and 1 percent NaCl were the selected fluids for oil and water phases, respectively.

c. Measure brine resistance. Compute brine resistivity (R_w).

d. Connect the core holder to the system, as shown in figure 1. Fill the annulus of core holder with overburden fluid (hydraulic pump fluid) at 500 psi. Insert core inside core holder. Apply vacuum to the core inside the core holder for 30 min. Fill the core with carbon dioxide gas to displace any air still present in the system. CO_2 solubility in water is higher than air solution in water; therefore, 100 percent brine saturated core is easy to achieve if CO_2 is present instead of air. Vacuum core again for 30 minutes. Saturate core with brine. Flow oil and water at selected ratios of brine and oil rates so that a drainage process is followed. Initially, a low flow rate should be used so that a wide range of brine saturations (100 percent to irreducible water) is achieved. Take desirable measurements after steady-state is reached, which means no change in pressure drop along the core sample is observed.

Step 2 -- <u>Installation of heating tape</u>

To measure the core resistivities at elevated temperatures, wrap heating tape around the core holder. Control the temperature of heating tape through a voltage transformer. Measure the temperature of tested system with a thermocouple inserted into the core holder.

Step 3 -- <u>Application of overburden and pore pressures</u>

Apply the selected overburden pressure to the core sample through hand operated hydraulic pump. Control the pore pressure of core using metering pumps and a backpressure regulator. Keep the overburden pressure greater than the pore pressure by least 100 psi.

Step 4 -- <u>Core resistance measurements</u>

After selected temperature and pressures are achieved, measure the core resistance using the LCR meter. To measure the core resistance using the four-electrode technique, apply current to the electrodes located outside the core holder and measure the voltage drop between the two electrodes inside the core holder. Compute true resistivities, R_t, true resistivity at a given brine saturation, and R_0 resistivity at 100 percent brine saturation from resistance measurements.

Step 5 -- Brine/soltrol saturation determination

To calibrate the core sample for x-ray absorption measurements, obtain x-ray scan along the dry core and the core 100 percent saturated with brine (tagged with 15 percent sodium bromide) inside the aluminum core holder. This calibration curve will be used to determine unknown brine/soltrol saturation in core samples.

LITERATURE ON ROCK RESISTIVITY MEASUREMENTS.

The literature was reviewed for available resistivity measurements. These data will be used to compute residual oil saturation. Then, errors in oil saturation determination will be determined after newly developed corrections for Archie's equation and similar equations are considered. The following data (field and laboratory) on rock resistivity were collected from the literature.

1. Formation factor (F) and cementation factor (m):

   - J. E. Carothers[1] reported a total of 981 measurements of formation factor data (793 in sandstone rocks and 188 in carbonate rocks).

   - A. M. Borai[2] presented both log and core data necessary to calculate m in low-porosity carbonates.

   - Additional F and m data were found from Focke and Munn,[3] Sethi,[4] and Rajga-Clemenceau.[5]

2. Saturation exponent (n):

- Walther[6] presented an n value calculated using log and laboratory measurements.

- Other studies in this area have been published by Worthington et al.,[7] and Miyairi et al.[8]

3. Rock resistivity in shaly sand:

- Koerperich's paper[9] is unique in providing both field data of resistivity log and laboratory data of water saturation, clay content, and formation porosity.

- Waxman and Smits,[10] and Hill and Milburn[11] provide a good insight into the effect of clay content on rock resistivity using laboratory measurements.

- Fertl[12] provides further data on shaly sand evaluation by use of rock resistivity measurements.

4. Effect of pressure and temperature on rock resistivity:

- Timur et al.,[13] analyzed the pressure dependence of electrical conductivity of brine-saturated sandstones from the data measured by Fatt,[14] Glumov et al.,[15] and Brace.[16] Fatt found that formation factor of brine-saturated sandstone increased as much as 35 percent under a net overburden pressure of 5000 psi. Glumov and Brase reported a resistivity behavior under pressure similar to that reported by Fatt.

- Waxman and Thomas,[17] reported the effect of temperature on resistivity measurements of shaly sandstone. Dolka[18] showed that both the formation resistivity and the saturation exponent decreased with temperature increase for sandstone in Saudi formation.

ROCK SAMPLES AVAILABLE FOR RESISTIVITY STUDY

During this 2-year research project, a minimum of five different rock types will be evaluated. Berea and Teapot Dome sandstone outcrop rocks are being evaluated at the present. Some of the other rocks available are as follows.

- Shannon outcrop rock (sandstone)
- Cottage grove (sandstone)
- Alundum (synthetic alumina)
- Bedford stone (limestone)
- Sandstone of Well 1-33 Obergfell, Putnam SE area, Red River Basin, Montana
- Sandstone of Well 31-1 Federal, Williston Basin, South Dakota

Several rocks will be evaluated for this research. The FY87 Annual Plan includes a study of carbonate rocks, and a search for more carbonate rocks is in progress.

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